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Eastern Environmental Radiation Facility, Montgomery, Ala

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16. Abstract

ABSTRACT

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Exposure measurements made with Pressurized Ionization Chambers (PIC's) at several distances and in several directions from the turbine building indicated that ^{16}N "skyshine" rather than direct gamma exposures contributed the major portion of environmental exposures.

Power level and distance dependencies were determined and a predictive model indicated that a distance of 360 meters and a power level of 801 MW(e) would yield a dose rate of 10 mrad/yr.

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^{16}N SKYSHINE SURVEY AT A 2400 MW(t) NUCLEAR POWER PLANT

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs

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N SKYSHINE SURVEY AT A 2400 MW(t) NUCLEAR POWER PLANT

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DECEMBER, 1975

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FOREWORD

The Eastern Environmental Radiation Facility (EERF) participates in the identification of solutions to problem areas as defined by the Office of Radiation Programs. The Facility provides analytical capability for evaluation and assessment of radiation sources through environmental studies and surveillance and analysis. The EERF provides technical assistance to the State and local health departments in their radiological health programs and provides special analytical support for EPA Regional Offices and other federal government agencies as requested.

This study is one of several current projects which the EERF is conducting to assess environmental radiation contributions from fixed nuclear facilities.

Charles R. Porter
Director
Eastern Environmental Radiation Facility

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ABSTRACT

A field study was executed to determine environmental levels, distribution, and composition of turbine-contributed ^{16}N gamma radiation from an operating boiling water reactor electric generating plant.

Exposure measurements made with Pressurized Ionization Chambers (PIC's) at several distances and in several directions from the turbine building indicated that ^{16}N "skyshine" rather than direct gamma exposures contributed the major portion of environmental exposures.

Power level and distance dependencies were determined and a predictive model indicated that a distance of 500 meters and a power level of 801 MW(e) would yield a dose rate of 10 mrad/yr.

^{16}N Skyshine Survey at a 2400 MW(t) Nuclear Power Plant

Introduction

The ^{16}N dose from the turbine building of a boiling water reactor can be considered to be composed of direct and scattered components. The direct component is from full energy photons not affected by shielding or air scatter. The scattered component is due to small- and large-angle (skyshine) scattered photons. The small-angle scatter is primarily the result of interactions along the line of sight between source and receptor. The large-angle or skyshine component is a result of large-angle photon scatter by air molecules. At plants which have turbine buildings with substantial side shielding and open tops, skyshine can be the principal source of ^{16}N exposure.

Several studies have been conducted to assess the dose rate from ^{16}N in the vicinity of a nuclear power reactor (1,2,3). In each of these direct radiation comprised some significant portion of the ^{16}N exposure. Typical plans for future boiling water reactors incorporate extensive side shielding for all components above the operating floor of the turbine generator building and some top shielding as well, if deemed necessary. The direct component of ^{16}N dose from such plants should be minimal. In contrast to earlier designs, where the principal source of ^{16}N gammas was the high pressure turbine and its associated steam lines, newer designs locate the moisture separators (typically combined with reheaters) above the operating floor making them the greatest potential source. In order to assess the ^{16}N doses from such a plant, a joint survey was conducted at the site of the Cooper Nuclear Power Station in Brownville, Nebraska. An initial survey was conducted on February 11 - 15, 1975, using instrumentation from the EPA Eastern Environmental Radiation Facility (EERF) in Montgomery, Alabama. A follow-up survey was performed April 21 - 24, 1975, primarily with instruments from the ERDA Health and Safety Laboratory (HASL), New York City, New York.

Site Information

The Cooper Nuclear Power Station is an 801 MW(e) base-loaded nuclear power plant utilizing a 2400 MW(t) boiling water reactor. High density concrete walls (figure 1) shield the components above the operating floor (turbines, moisture separators, and associated steam lines) along a line-of-sight to the outside environment on the north, east, and west sides of the building. Components other than the moisture separators are only partially shielded to the south. The terrain to the north of the turbine building is relatively flat and unobstructed allowing measurements to be made from the walls of the turbine generator building to distances of 500 to 600 meters. The Missouri River flows along the east side of the plant with the plant property extending to the east of the river as shown in figure 1. Access to this part of the site is difficult. The terrain to the south of the plant is slightly rolling, but measurements could be made to distances of a few hundred meters from the turbine generator building. The reactor building and switchyard to the west of the turbine building precluded profile measurements in that direction.

Field Measurements

The February measurements were intended to provide an overall indication of the ^{16}N radiation at different locations on the plant site as well as to provide an estimate of the background exposure rate. Measurements were made primarily with

Figure 1. Turbine building operating floor

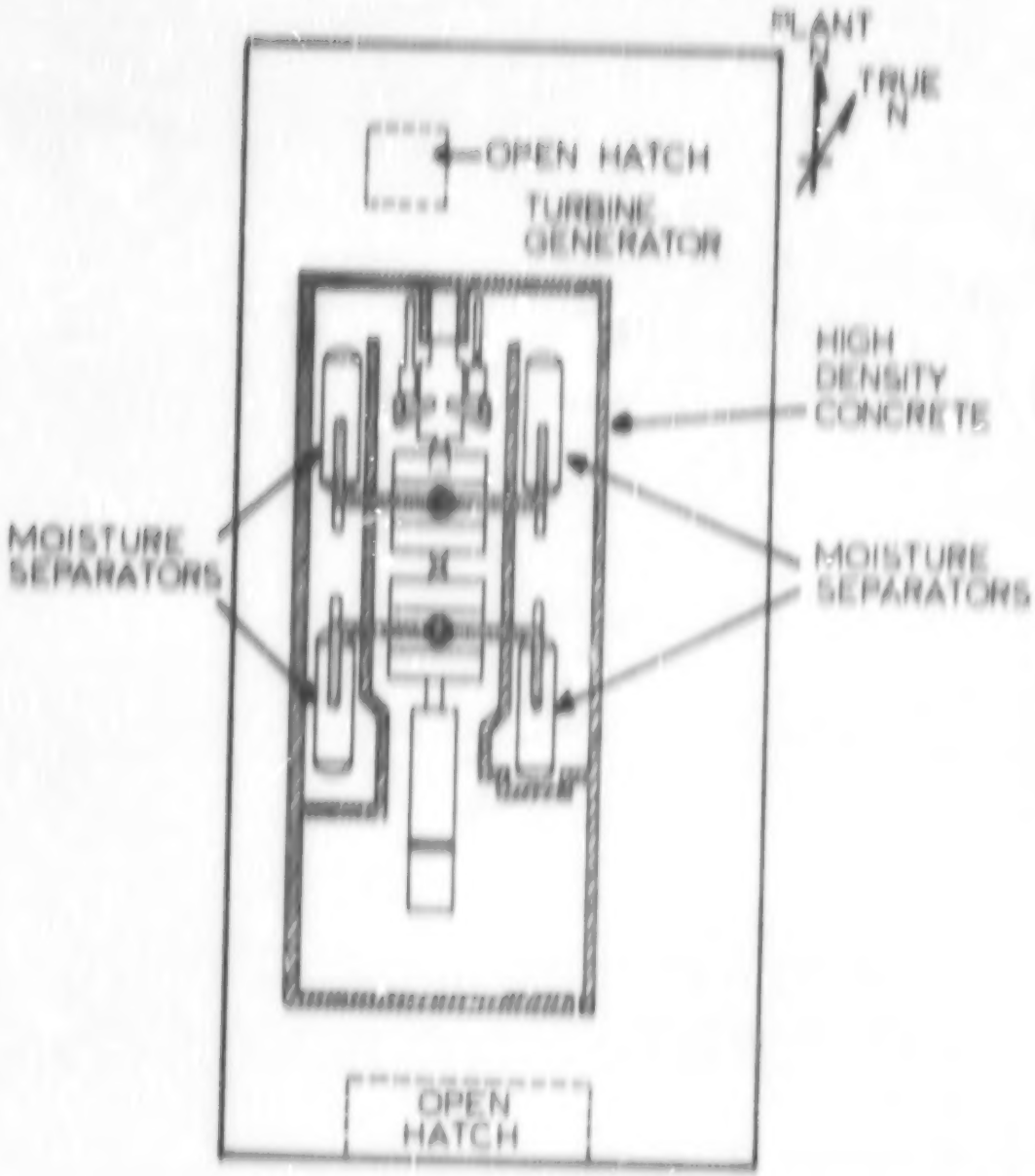
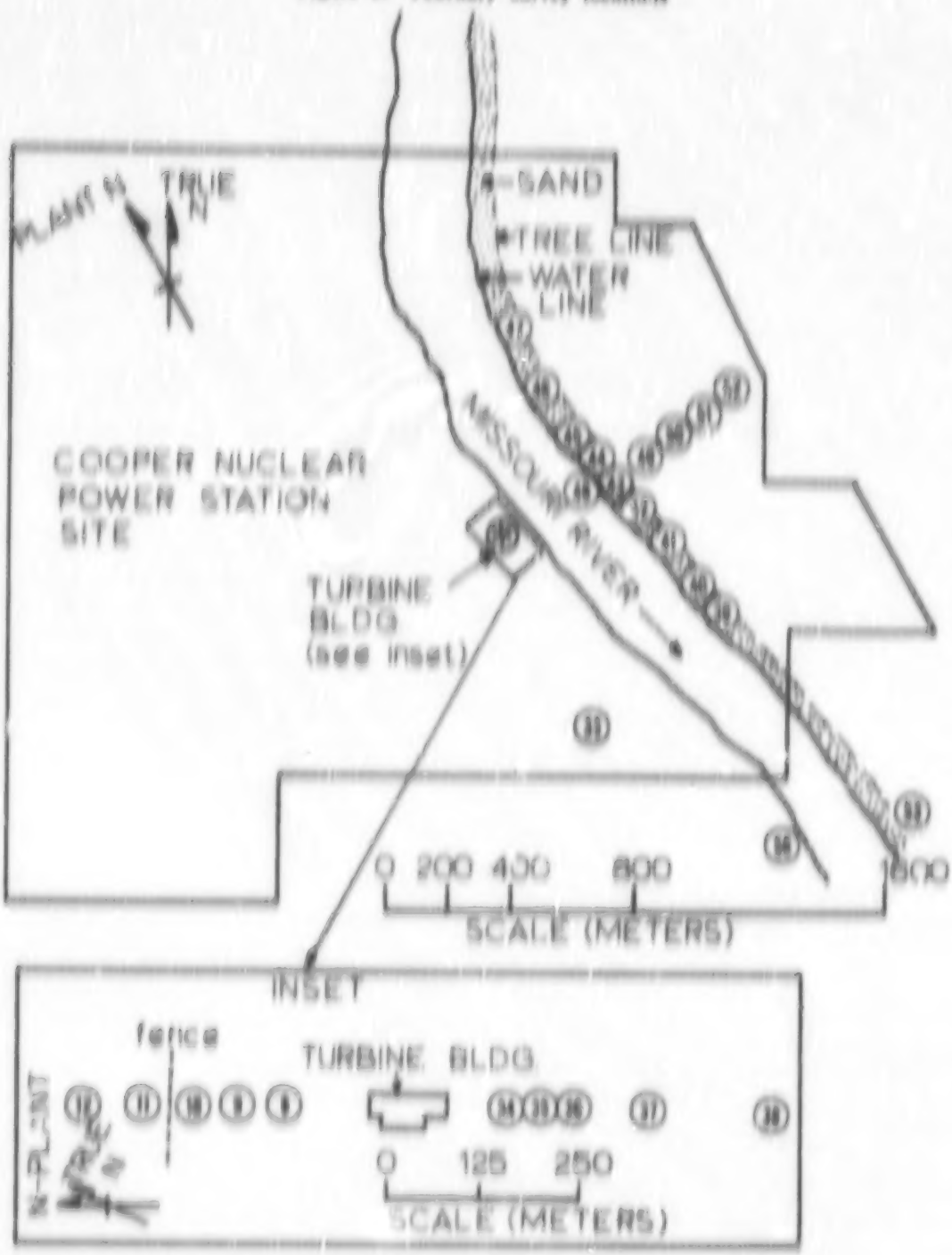


Figure 3. February survey locations



pressurized ionization chambers (PIC's) which had been previously calibrated at the EERF using an NBS-certified ^{226}Ra source. Spectral measurements were made at some locations using a 10-cm x 10-cm NaI(T1) detector in conjunction with a multichannel pulse-height analyzer. Exposure rate profiles were made along the turbine axis north and south of the plant. A partial profile perpendicular to the turbine axis east was made but was limited to those locations accessible on either side of the river. North-south profiles were also obtained along each side of the river centered on this east axis. Several measurements were also made on the roof of the cooling water intake structure, located to the east of the turbine generator building. The roof of this building is above the floor of the turbine generator building and therefore provided a location close to the source shielded only by the side walls. Additional measurements were made near the river bank at Brownsville State Park (About 4 km north of the plant) to provide an estimate of local background. Data from this survey are shown in table 1. The survey locations are indicated on figures 2, 3 and 4. A short time prior to the survey the plant had shut down for an inspection, and at the time of the survey was in the process of returning to its normal operating level. The power level was increasing gradually from 76% to 90% of full power over the period of the study, except for a brief period during measurement 63 when it was temporarily reduced. Measurements at location 7 were taken at several power levels to observe exposure rate dependence with power level.

During the follow-up survey (April 23 to 24), a complete profile of ^{16}N exposure rates was obtained in the northerly direction along the turbine axis, as well as a partial profile along the south axis. Difficulties in gaining access to the east shore of the river prevented measurements perpendicular to the turbine axis. The data for this survey are shown in table 1 (Measurements B1-B17) and table 2. The reactor operated at 2355 MW(t) during this portion of the study, except for a brief drop to 60% of full thermal power during the night of April 23-24. Measurements were made primarily with PIC's. NaI(T1) and Ge(Li) measurements were made at selected locations to assess terrestrial background and to detect any direct component of the ^{16}N exposure. In order to provide an intercomparison between the February and April data a few measurements using an EERF PIC were also made. There were no indications of any exposure from other sources associated with the reactor, including the plume, during either measurement period.

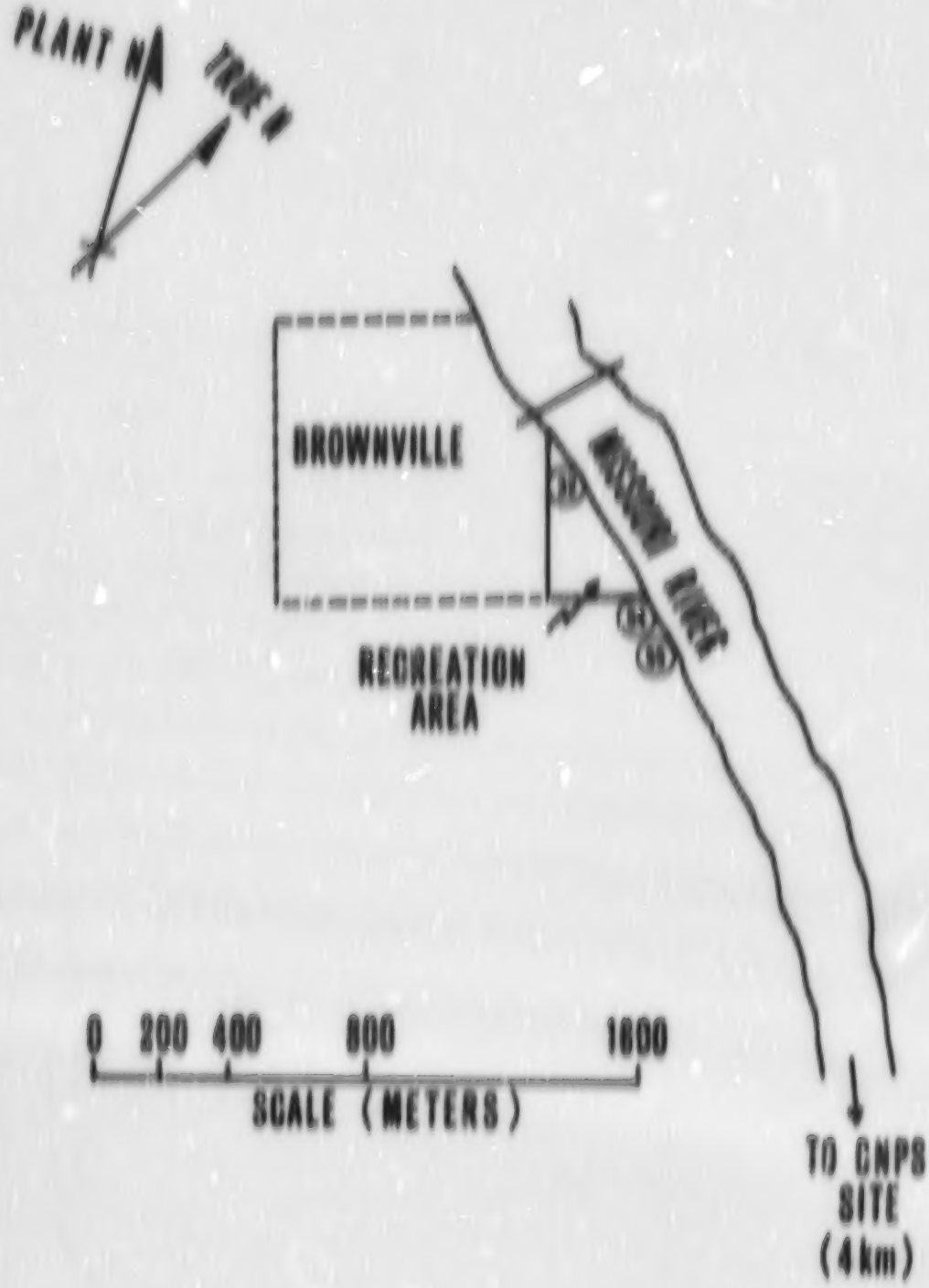
Analysis of Data

Evaluation of Spectral Data

Spectroscopic data indicated the presence of some high energy photons in the profiles taken to the south and to the east. In the case of the south data, these are to be expected due to the partial shield wall. In the east direction it would appear that the shield wall is thin enough to permit direct radiation to make a small contribution to the ^{16}N exposure rate. Even though they contain some direct radiation, the exposure rates to the south and east are of the same order of magnitude as exposure rates at corresponding locations to the north. Because of its lack of any direct component the north profile was used to evaluate skyshine.

Figure 3. February on-site survey locations

Figure 4. February northern survey locations



Background Considerations

Background from terrestrial and fallout gamma emitters was estimated by analyzing spectroscopic data obtained during the April portion of the survey.[1] Net ^{16}N levels were calculated by subtracting from the HASL ion chamber total readings (1) a 3.9 μR/hr cosmic ray background and (2) the estimated gamma background based on spectrometric measurements at the same or a nearby location. There is an apparent discrepancy between the PIC and spectrometer gamma exposure rates for the measurement at 981 meters south of the plant (table 2). For this location the ^{16}N level was estimated from the 511 keV annihilation radiation peak in the Ge(Li) spectrum as calibrated with data from other locations. EPA ion chamber data in the vicinity of the plant were corrected using an 8.3 μR/hr background (3.9 μR/hr cosmic + 4.4 μR/hr gamma). It was assumed for these measurements that the background did not change appreciably from location to location or from February to April. In this regard it should be noted that the total exposure rates at the Brownsville State Park (9.4 μR/hr - EPA, Feb.; 9.3 μR/hr - HASL, April; and 9.3 μR/hr - EPA, April), are consistent from February to April but are about 1 μR/hr higher than the levels inferred for typical on-site locations.

Intercomparison of EPA/HASL Data

In addition to the 9.3 μR/hr (EPA) vs. 9.3 μR/hr (HASL) values at Brownsville State Park, the values 87.7 μR/hr (EPA) and 85.6 μR/hr (HASL) for essentially the same location (#7) compare closely. Instrumental problems prevented additional comparisons.

Power Level Dependence

Lowder (1) has proposed a power level dependence for ^{16}N exposures from power reactors of the form $d = d_0 p \exp(-\lambda t_0/p)$, where d_0 is the exposure rate that would result at full power with no reactor/turbine building delay, p is the fraction of full power, λ is the decay constant for ^{16}N, and t_0 is the effective decay time between the reactor and those turbine building components which comprise the ^{16}N source. This model assumes (1) that the concentration of ^{16}N steam (μCi/g) leaving the reactor is independent of power level, (2) the steam flow rate (g/s) is proportional to power level, and (3) that the effective time for ^{16}N decay in the source components does not depend on power level.

The data for location 7 were used to determine least squares estimates of d_0 and t_0. The results of this least squares fit are shown in table 3. The limited range of power variation introduces a high correlation between the parameters (.9951) and large standard deviations in their estimates. While the model and its assumptions cannot be considered verified on the basis of such limited data, the model does provide an adequate empirical description of the data. The effective steam delay time of 7.0 seconds at full power is comparable to the value (8 seconds) Lowder, et al. obtained at Oyster Creek (1).

[1] The analysis of the HASL data will be contained in the forthcoming publication, Lowder, et al., "Determination of ^{16}N Radiation Field at a BWR Power Station."

Distance Dependence

A theoretical model of the skyshine would require transport calculations beyond the scope of this study. Instead the following empirical model was used:

$$d = \frac{A_0 P \exp(-\lambda \tau_0 / p) P_0}{4 \pi r^2} \exp(-r/\lambda)(1 + b\, r/\lambda)$$

where: d = the ^{16}N exposure rate ($\mu R/hr$)
A_0 = a conversion factor [$\mu R \cdot m^2/hr$ per MW(e)]
P = the fraction of full power
P_0 = the full plant power (MW(e))
λ = the decay constant for ^{16}N (s^{-1})
τ_0 = the effective delay time at full power (seconds)
r = the distance between the receptor and the center of the moisture separators (meters)
λ = an effective attenuation length (meters)
b = an effective linear buildup factor

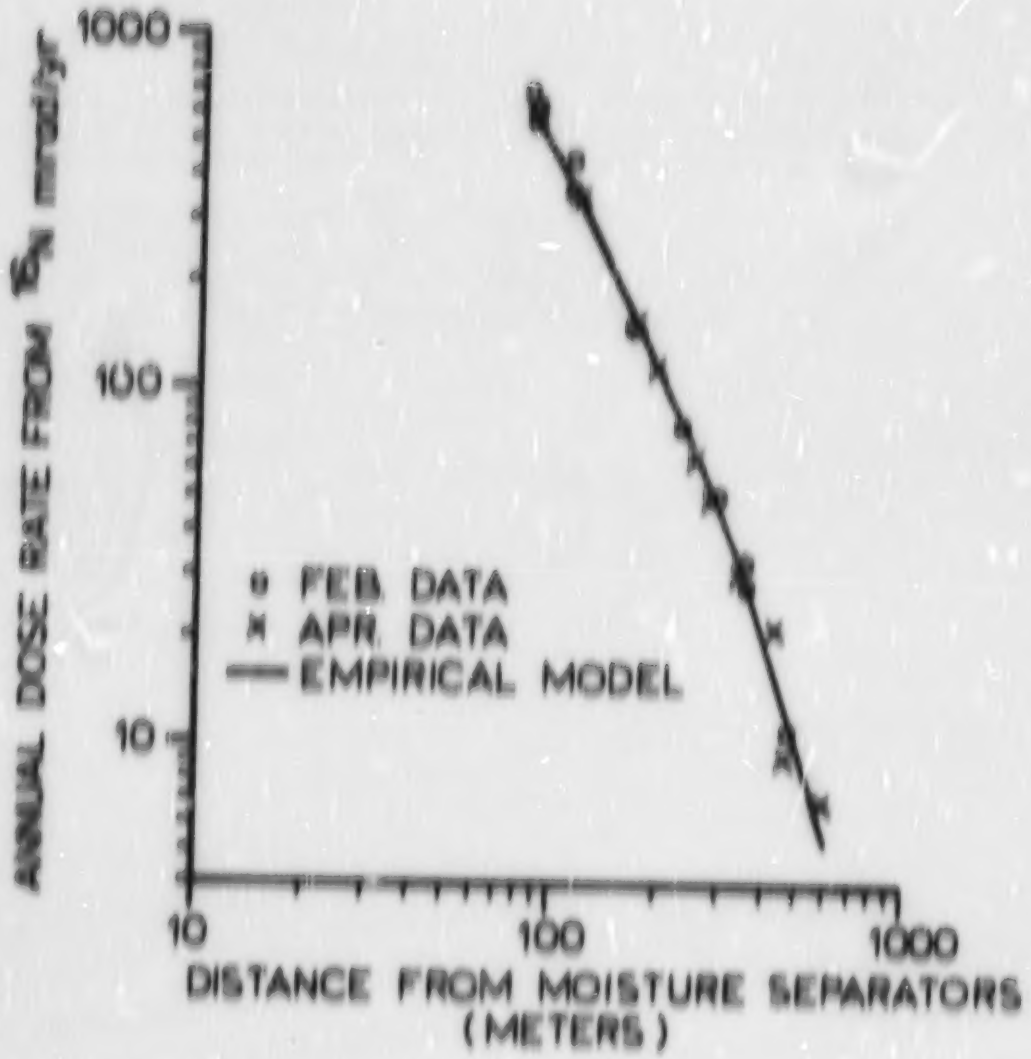
This model combines the power dependence model from the previous section with a point source model corrected for attenuation and linear buildup.

The least squares fit of the distance data is summarized in table 4. Annual ^{16}N dose rates based on the empirical model and the observed data are plotted in figure 9. Exposure rates have been converted to dose rates using a conversion factor of 1 $\mu R/hr$ = 7.688 mrad/yr. The February data have been adjusted to full power using the assumed power dependence model. Note that while the fitted model predicts a dose rate of 10 mrad/yr at 500 meters there is considerable scatter of the observed data about the model at this distance. The standard deviation of the calculated value at 457 meters is 2.5 mrad/yr. Since this value assumes no error contribution from the background determination or the model itself, it is a lower limit for the uncertainty of the dose rate at this distance. The absolute values of the correlation coefficients between parameters are all high ($> .9$) so that while the model provides a reasonable description of the data, there are substantial uncertainties in individual parameters. The calculated linear buildup factor (3.0) is extreme for an unshielded source, but is not unreasonable for this situation where the doses are essentially from radiation scattered through large angles.

Summary

Spectrum strip measurements made north of the turbine generator building at Cooper Nuclear Power Station indicated that plant doses were predominately from ^{16}N skyshine. The power level dependence observed was consistent with a model assuming a constant concentration of ^{16}N reactor steam and a reactor-turbine building delay inversely proportional to power level. A $1/r^2$ distance model with attenuation and buildup was fitted to the data. At a distance of 500 meters a dose rate of 10 mrad/yr at 801 MW(e) is predicted. The lower bound for the standard deviation of this estimate is 2.5 mrad/yr. Both the power level and distance models were chosen to provide an empirical fit to the data but do not have any rigorous basis for their choice.

Figure 8. Annual ^{16}N dose rates at full power vs. distance (North Axis)



Since the dose rate will depend on the particulars of the turbine building components and shield configuration, it would be inappropriate to rely solely on the use of the empirical models of this study to predict doses from other plants. However, the data invite comparison to a more detailed analysis, which would have to include source term as well as transport modeling.

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(2) BRINCK, W., K. GROSS, O. GELS and J. PARTRIDGE, "Environmental Radiation Study at Vermont Yankee," presented at the Nineteenth Annual Meeting of the Health Physics Society held in Houston, Texas, (July 1974).

(3) HAIRR, L. M., P. C. LECLARE, T. W. PHILBIN, and J. R. TUDAY, "The Evaluation of Direct Radiation in the Vicinity of Nuclear Power Stations," 18th Annual Health Physics Meeting, (June 1973).

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Table 1

EPA
Pressurized Ionization Chamber measurements
Cooper Nuclear Station - February 1978

Measurement Number	Location	Time & Date	Gross Exp. Rate (μR/hr)	Approx. Power Level (MWe)
1	1 m north of Turbine Bldg on center line	1111 2/12/78	45.1	606
2	61 m north of Turbine Bldg on center line	1210 2/12/78	57.6	611
3	30 m from north end of Turbine Bldg at 67°	1308 2/12/78	55.9	612
4	30.5 m north of Turbine Bldg on center line	1404 2/12/78	64.4	612
5	31.7 m from north end of Turbine Bldg at 115°	1512 2/12/78	51.6	612
6	45 m from north end of Turbine Bldg at 60°	1609 2/12/78	46.9	612
7	57 m north of Turbine Bldg on center line	1715 2/12/78	58.4	612
8	117 m north of Turbine Bldg on center line	1830 2/12/78	80.5	612
9	181 m north of Turbine Bldg on center line	1935 2/12/78	14.1	612
10	244 m north of Turbine Building on center line	2050 2/12/78	12.4	614
11	305 m north of Turbine Bldg on center line	2211 2/12/78	10.6	617
12	427 m north of Turbine Bldg on center line	2430 2/12/78	9.2	617
13	Northwest corner of Intake Bldg on line with north end of Turbine Bldg	1651 2/13/78	63.9	617
14	18.3 m east of Turbine Bldg just south of Intake	1835 2/13/78	121.1	617
15	Center of Intake Bldg East of Turbine - ground level	1940 2/13/78	82.7	617
16	Southwest corner of Intake Bldg - ground level	1945 2/13/78	106.8	617
17	12.2 m east of Turbine Bldg on line with south end of Intake	1950 2/13/78	118.4	617
18	21.3 m east of Turbine Bldg and 21.9 m south of Intake Bldg	1950 2/13/78	81.9	617
19	21.3 m east of Turbine Bldg and 18.3 m South of Intake Bldg	1958 2/13/78	83.4	617
20	Top of first level of Intake Bldg - southwest corner	1958 2/13/78	114.4	617
21	Top of upper level of Intake Bldg - southwest corner	1958 2/13/78	130.4	617
22	Top of upper level of Intake Bldg of West side	1910 2/13/78	118.4	617
23	Top of upper level of Intake Bldg - northwest corner of Bldg	1918 2/13/78	94.0	617
24	Top of upper level of Intake Bldg - northeast corner of Bldg	1920 2/13/78	68.6	617

Table 1
(Cont.)

EPA
Pressurized Ionization Chamber measurements
Cooper Nuclear Station - February 1975

Measurement Number	Location	Time & Date	Gross Exp. Rate (μR/hr)	Approx. Power Level (MWe)
35	Top of upper level of Intake Bldg - southeast corner of Bldg	1700 2/13/75	97.8	617
36	31.7 m east of Turbine Bldg on line with south end	1708 2/13/75	40.9	617
37	31.7 m east of Turbine Bldg even with north edge of Waste Vault	1715 2/13/75	50.1	617
38	East edge of sludge pond even with stack	1730 2/13/75	47.1	617
39	South edge of Sludge Pond on line with West side of Intake Bldg	1735 2/13/75	17.7	617
40	South end of Turbine Bldg at edge of building on center line	1740 2/13/75	36.4	617
41	South end of Turbine on center line even with Waste Vault	1745 2/13/75	33.8	617
42	Park at Park near Brownville, northeast, taken with Rad	1810 2/13/75	9.4	617
43	327 m south of Turbine Bldg at gate on levee	(930) 2/13/75	9.4	664
44	79.7 m south of Turbine Bldg near center line	(940) 2/13/75	33.6	664
45	104 m south of Turbine Bldg near center line	(944) 2/13/75	33.5	664
46	128 m south of Turbine Bldg near center line	(950) 2/13/75	30.7	664
47	180 m south of Turbine Bldg at high voltage tower	(955) 2/13/75	13.0	664
48	405 m south of Turbine Bldg near center line	(700) 2/13/75	10.7	664
49	West bank of river under high voltage lines	(00) 2/13/75	8.9	664
50	West bank of river between locations 49 and 51	(10) 2/13/75	10.8	666
51	West bank of river directly across river from stack	(15) 2/13/75	11.7	667
52	West bank of river directly across river from south end of Turbine Bldg	(25) 2/13/75	13.1	667
53	West bank of river directly across from center of Turbine	(40) 2/13/75	13.1	668
54	West bank of river - directly across from north end of Turbine Bldg	(45) 2/13/75	13.1	669
55	West bank of river - directly across from 91 m fence	(53) 2/13/75	11.7	670
56	West bank of river - directly across from 274 m fence	(00) 2/13/75	9.9	670
57	West bank of river - 131 m North of location #46	(09) 2/13/75	9.7	670
58	30.5 m West of location #41 94.8 m from east Tree line (on top)	(35) 2/13/75	9.6	670
59	67.1 m east of #41 in trees on east Bank (approx. 7.6	(35) 2/13/75	10.1	670

Table 1
(Cont.)

EPA
Pressurized Ionization Chamber measurements
Cooper Nuclear Station - February 1978

Measurement Number	Location	Time & Date	Gross Exp Rate (μR/hr)	Approx. Power Level (MWe)
	on snow)			
50	120 m east of #41 in trees on east side (approx. 7.6 cm snow)	1340 2/15/78	9.6	670
51	180 m east of #41 in trees on East side (approx. 7.6 cm snow)	1350 2/15/78	9.4	670
52	On top of levee 1097 m east of Turbine Bldg. (approx. 7 cm snow)	1330 2/15/78	9.5	672
53	Background in woods south of Plant on east side of river	1350 2/15/78	9.4	672
54	On West Sand Bar 305 m south of Brownville State Recreation Area - background	1400 2/15/78	9.5	674
55	On West Sand Bar approx. 198 m South of Brownville State Recreation Area	1311 2/15/78	9.4	674
56	South of Plant on East bank of river - sand bar - background	1300 2/15/78	9.0	676
57	305 m North of Turbine on center line - reiske of #11	1430 2/15/78	11.5	676
58	30.5 m North of Turbine Bldg on center line - reiske of #7	1601 2/15/78	60.5	669
59	79.6 m from north end of Turbine Building at 67.5° - reiske of #1	1610 2/15/78	69.5	669
60	3 m north of Turbine Bldg on center line - reiske of #1	1618 2/15/78	53.5	669
61	51.5 m from north end of Turbine Bldg at 112° - reiske of #1	1621 2/15/78	73.5	668
62	61 m north of Turbine Bldg at center line - reiske of #1	1700 2/15/78	68.5	666
63	30.5 m north of Turbine Bldg on center line - reiske of #1	0800 2/16/78	70.5	731
	By Pass Valves opened during measurements	0801 2/16/78	69.5	"
		0811 2/16/78	69.5	"
		0820 2/16/78	69.4	"
		0831 2/16/78	77.5	731

Table 1
(Cont.)

EPA
Pressurized Ionization Chamber measurements
Cooper Nuclear Station - April 1975

Measurement Number	Location	Time & Date	Gross Exp. Rate (μ R/hr)	Approx. Power Level (MWe)
B- 1	Upper Roof of Intake Bldg northwest corner (repeat of #21 on 3/13)	1057 4/22/75	~ 100	798
B- 2	Upper Roof of Intake Bldg (repeat of #3) on 3/13)	1109 4/22/75	~ 100	798
B- 3	Upper Roof of Intake Bldg - northwest corner (repeat of #21 on 3/13)	1111 4/22/75	107.0	798
B- 4	Upper Roof of Intake Bldg - northwest corner (repeat of #25 on 3/13)	1117 4/22/75	107.0	798
B- 5	Upper Roof of Intake Bldg - southeast corner (repeat of #25 on 3/13)	1130 4/22/75	107.0	798
B- 6	457 m north of Turbine Bldg on center line	1150 4/22/75	10.0	798
B- 7	351 m south of Turbine Bldg under north edge of high voltage tower	1400 4/22/75	14.0	798
B- 8	Northeast corner of Intake Bldg (on line with north end of Turbine Bldg (repeat of #13 on 3/13)	1417 4/22/75	109.0	798
B- 9	30.5 m north of Turbine Bldg on center line (repeat of #7 on 3/13)	1603 4/15/75	87.9	798
B-10	Brownville State Recreation Area (repeat of #10 on 3/13)	1634 4/22/75	9.1	798

Table 3

Health and Safety Laboratory survey data - Cooper Plant

April 1978

Distance to Turbine Bldg. (meters)	Detector	^{41}A	Gamma Exposure Rate (μR/hr)					
							Total	^{41}A
North Axis								
37	PIC						81.7	77
67	PIC						49.4	45
122	PIC*						34.3	30
	PIC**						38.3	36
146	PIC						19.7	15.6
	GM(LI)	3.0	1.0	1.1	<0.1	(4.1)		
206	PIC						13.7	8.4
	GM(LI)	3.3	0.9	1.1	<0.1	(4.3)		
235	PIC						10.9	6.5
297	PIC						8.5	4.1
	GM(LI)	3.5	0.9	1.1	<0.1	(4.4)		
364	PIC						6.9	3.8
	Nal	3.1	0.6	0.9		(4.1)		
437	PIC						5.7	1.8
	GM(LI)	3.7	1.0	0.8	<0.1	(4.5)		
569	PIC						3.4	0.9
	Nal	3.5	0.7	0.9				
	GM(LI)	3.4	0.9	1.1	<0.1	(4.5)		
1080	PIC						3.1	<0.1
	Nal	1.8	1.0	1.5		(3.3)		
	GM(LI)	1.9	1.1	1.6	<0.1	(4.0)		
South Axis								
103	PIC						9.0	6.1
	GM(LI)	3.4	0.9	1.1	<0.1	(4.5)		
267	PIC						7.3	
370	PIC						7.4	
475	PIC						5.1	1.0
	GM(LI)	3.5	1.1	1.1	<0.1	(4.8)		
581	PIC						3.6	1.7
	GM(LI)	1.7	1.1	1.1	<0.1	(3.9)		

* 1 meter above ground
** 15.2 meters above ground

Table 3

Least squares estimation of power variation parameters

Model:

$$d = d_0 \rho \exp(-\lambda t_0/\rho)$$

Parameters: $(1/\lambda = 10.53$ seconds

$d_0 = 134 \pm 28$ μR/hr*

$t_0 = 7.0 \pm 1.8$ seconds*

d cal (μR/hr)	d obs (μR/hr)	ρ
97.6	98.4	704
88.8	89.8	855
78.2	79.2	913
81.0	83.6	950

Mean square error of fit = 4.4 (μR/hr)²

The data are for location 7 and assume a total background of 9.3 μR/hr. Least Squares fit calculated using [illegible]

* 1 standard error

Table 4

Least squares estimates of distance variation parameters

Model:

$$d = \frac{a_0 P}{4\pi r^2} \exp(-\lambda t_0/\rho)\, P_0 \exp(-r/\ell)(1 + br/\ell) + B.G$$

$1/\lambda = 10.53$ m

$P_0 = 801$ MWe

$t_0 = 7$ m

Parameters:

$a_0 = 1.8 \pm .37^{\dagger} \times 10^5 \quad \frac{\mu R \cdot m^2}{MWe \cdot hr}$

$\ell = 230 \pm 54^{\dagger}$ meters

$b = 3.0 \pm 1.5^{\dagger}$

$d_{cal} \pm 0.3\dagger$ (μR/hr)	$d_{obs} \pm 0.3\dagger$ (μR/hr)	r (meters)	P	H_{cal} (mrad/yr)
58.9	57.8	110	765	335
66.5	66.4	80	764	431
57.2	58.4	98	764	370
51.0	50.5	108	764	100
14.9	14.7	232	764	84.5
13.1	12.4	291	767	80.0
10.6	10.6	356	770	17.7
9.2	9.2	420	770	2
11.0	11.5	356	861	20.9
62.3	65.0	88	855	401
68.0	62.5	110	856	389
75.0	79.2	88	913	517
86.3	87.1	86	936	601
90.0	85.3	83	936	630
46.6	51.3	115	936	336
28.4	28.3	168	936	161
24.2	23.9	192	936	121
16.9	16.7	252	936	66.6
14.8	14.8	304	936	49.7
12.5	12.4	361	936	34.4
10.5	11.1	430	936	15.7
10.0	9.8	457	756	13.0
9.0	9.2	505	936	9.2

† One standard error

‡ Background
1 μR/hr = 7.888 mrad/yr
Mean square error of fit = 4.0 (μR/hr)^2

The data fitted are for the north pair of both the February and April surveys. A background of 0.1 μR/hr was added to the net HASL data and assumed for the EPA data for purposes of the fit. r is taken as the distance between the center of the moisture separators and the north wall of the turbine building (49 m). Least squares fit calculated using BMDX67[8.4].